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AUTHOR Mumaw, Randall J.; And Others
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ABSTRACT

Twenty-eight engineering students were presented with complex spatial problems to investigate the effects of spatial aptitude and strategy selection on problem solving. Aptitude was determined by spatial aptitude test scores and strategy was determined by verbal reports and latency measures. It was found that aptitude determined the efficiency with which certain strategies could be utilized. (Author)

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INDIVIDUAL DIFFERENCES IN COMPLEX SPATIAL PROBLEM SOLVING: APTITUDE AND STRATEGY EFFECTS

Randall J. Mumaw
Lynn A. Cooper
Robert Glaser

University of Pittsburgh

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Our recent work has been concerned with determining the cognitive processes that underlie spatial aptitude. Most of the spatial aptitude tasks that we have developed process models for are composed of simple geometric shapes and require only a single spatial transformation. The process models developed for these tasks, therefore, are also fairly simple. However, these simple tasks, in the form of reference tests, have strong predictive validity for more complex "real-world" skills. One skill that is consistently well predicted by spatial aptitude tests is Engineering Drawing and Design. Today I will discuss our initial investigations into this complex spatial task.

Mechanical Engineers and Draftsmen use two conventional forms to represent 3-dimensional objects. The first, called an isometric drawing, is similar to a perspective drawing of the 3-dimensional object. (an example is given on the left-hand side of Figure 1 of your handout). The second type of representation, called the orthographic projections, shows projections of tne 3-dimensional object onto 3 2-dimensional planes. (Figure 1 also shows the orthographic projections of the given isometric drawing). For the purpose of presentation, I will refer to the drawing of the block as the 3-dimensional drawing and the orthographic projections as 2-dimensional projections. These projections not only show the near faces of the object, but also represent the hidden far faces through the use of dashed lines. (Figure 2 shows a second drawing of a 3-dimensional object with its corresponding 2-dimensional projections, this time showing hidden lines.) The front, top and right side views are conventionally the three views used for the 2-dimensional projections.

Skill in Engineering Drawing requires the ability to use these two forms of representation and to be able to translate one into the other. In addition, it may be important to be able to construct either of the two forms from a verbal description of the object. To investigate these issues we created several verification tasks that require subjects to use one or two of these three forms of representation (namely, the drawing of the 3-dimensional object, the 2-dimensional projections, and the verbal description.) Specifically, the issues of interest are: 1) the relationship between spatial aptitude and accuracy on the problem solving task; 2) the occurrence of solution strategy differences and their relationship to accuracy on the problem solving task; 3) the identification of problem characteristics that interact with solution strategies to facilitate or inhibit solution success.

An example of the Engineering Drawing task that I will be discussing today is shown in Figure 3 of your handout. The subject is first shown the 2-dimensional projections with an empty frame replacing one of the three views. (In this example the right side view is missing.) When the subject is ready, he replaces this slide with a second slide, which presents a third view. The subject must determine if the right side view given is compatible with the 2 views presented on the first slide, where compatibility implies that all 3 views would correctly describe a real 3-dimensional object. The subject controls the slide alternation and can view each slide as often as he desires, however, the total viewing time is restricted to 80 seconds. After interviewing subjects used in a pilot study, we learned of two methods that could be used to solve this type of problem. The first is to determine compatibility by comparing and matching features of the separate 2-dimensional projections. A second solution strategy is the

use of the 3-dimensional drawing which corresponds to the first two views to integrate the third view with the first two.

Thirty problems were created which varied in solution difficulty. For each problem 7 dependent measures were collected. (These measures are listed in Table 1 on the handout.) They are: the number of looks at the 2 slides, total time to solution, time of first look at slide 1, time of first look at slide 2, time of further looks at slide 1, time of further looks at slide 2, and solution accuracy. After each set of 15 problems, subjects responded to questions about solution strategies and problem difficulty.

Twenty-eight students who had completed a course in Engineering Drawing and Design were used as subjects. The space relations tests from the Differential Aptitude Test and the Primary Mental Abilities battery were used to determine the spatial ability of the subjects. Fourteen of the 28 subjects scored above criterion scores on these two tests and 14 subjects scored below two other criterion scores, giving us a high spatial and a low spatial group. Interestingly, the range of spatial ability in this group is quite comparable to the general college population.

As stated previously, the two variables of main interest are spatial aptitude and solution strategy. To determine the solution strategy a subject used, we looked at retrospective verbal protocols and the patterns in the dependent measures within and across trials. The verbal protocols, as in the pilot work, fell into two general categories. Some subjects spoke of using the features of the 2-dimensional projections and others claimed to mentally construct the 3-dimensional drawing. From this information, we postulated how these two solution strategies might be manifested in the dependent measures.

We expected the number of looks and the time of first look at slide 1 to be the most revealing. Specifically, if the subject was mentally constructing a 3-dimensional drawing, we expected that a large percentage of his total time would be spent on slide 1 at the initial viewing. Also, if the missing view has been generated, few comparisons need to be made between slides 1 and 2, therefore requiring only a few alternations. Conversely, the subject who tries matching the features of the 2-dimensional projections should make many alternations between slides as each single feature is compared. In addition, a smaller percentage of his total time should be spent on the first viewing of slide 1, since he is only extracting a local feature. Table 2 in the handout is a summary of the patterns in the dependent measures for the two solution strategies. The Constructive strategy, that uses the 3-dimensional drawing, should show few looks and the ratio of time of look 1 at slide 1 over total solution time should be large, reflecting construction time. The Analytic or Feature Match strategy should show many looks and the time ratio should be smaller. Of the 28 subjects used, 13 showed a dependent measure pattern suggesting a Constructive strategy and 11 showed a pattern suggesting an Analytic strategy. Four of the subjects did not fit either pattern consistently.

The two independent variables, spatial aptitude and solution strategy, can now be related to task performance by looking at accuracy for each of the four groups of subjects. As the first slide shows, spatial aptitude does not predict task performance well at all. Both high and low aptitude subjects are less accurate on items rated more difficult, and there is no difference in accuracy level between the two groups. Similar results are found when the subjects are grouped by strategy type. The next slide shows virtually the same trends,

suggesting no differences in accuracy as a function of strategy selection. However, when subjects are grouped according to both aptitude and strategy, an interaction is suggested, such that low aptitude subjects using the Constructive strategy show poorest performance. This pattern is emphasized more strongly and becomes more interpretable when subject groups are further broken down based on the total time to solution, as shown in Table 3 of the handout. Subjects who had an average solution time of less than 50 seconds are placed in the "fast" cells. Those subjects who, on the average, took longer to solve the items are placed in the "slow" cells.

There are two important results to note in this Table. First, consider the relationship between aptitude level and strategy selection. Seven of the 11 high aptitude subjects chose an Analytic strategy and 9 of the 13 low aptitude subjects chose the Constructive strategy. This trend is in the opposite direction of what we might have expected. The second important result is the occurrence of a significant 3-way interaction which reveals an incompatibility between aptitude and strategy. To comprehend this complex table most easily, notice first the performance of the Constructive, high aptitude subjects and contrast this group with the low aptitude subjects using the same strategy. The Constructive, low aptitude subjects, who worked at the same speed, had an accuracy level that was half that of the Constructive, high aptitude subjects. The Constructive, low aptitude subjects, who took twice as long to solve the problems, however, obtained the same level of performance shown by the Constructive, high aptitude subjects. These trends are not found, however, for those subjects using an Analytic strategy. The performance of the low aptitude subjects was identical to the high aptitude subjects in accuracy and solution time.

This pattern of results suggests to us that there are some limits on the efficiency with which low aptitude subjects can use the Constructive strategy. For those subjects to perform as accurately as the high aptitude subjects, they must use twice as much time. In addition, when low aptitude subjects use a strategy that does not seem to depend on mentally constructing an isometric drawing, they are able to perform as efficiently as the high spatial aptitude subjects.

A third issue addressed in these data was the relationship between solution strategy and problem characteristics. We began this task analysis knowing little about the important characteristics of these problems or of these representations. However, by looking at the items on which one strategy group outperformed the other, we were able to locate some consistencies which suggest problem - strategy interactions. The Constructives seemed to be more accurate on items which have what we have come to call "emergent" properties. Figure 4 on the handout provides an example of this type of item. These are items in which there is little overlap in local features between slide 1 and slide 2. That is, it is necessary to construct the 3-dimensional drawing to determine the compatibility of the three views. Note that the second slide reveals an angled plane that is not shown on slide 1. Construction of the 3-dimensional drawing (also shown in Figure 4) allows the integration of these seemingly unrelated projections.

The set of items on which Analytics outperformed Constructives contained several items which were incompatible due to a reversal in the third view. That is, a bottom view is shown in the place of the top view or a left-side view is substituted for a right-side view. Figure 5 on the handout shows an example of the latter case along with the correct 3-dimensional drawing. This result suggests that Analytics may

be better at detecting discrepancies at the local feature level.

In summary, although our data analysis of these early experiments has been exploratory and our N's are small, we can begin to address the three issues I introduced earlier. First, we have discovered that there are individual differences in the way subjects solve these problems, and that this difference is tied to the use of the 3-dimensional drawing to mediate problem solution. Secondly, only 1 of the 3 tasks we have investigated have shown strong individual differences in accuracy due singularly to spatial aptitude. In the task just described, aptitude seems only to limit the efficiency with which subjects can utilize the Constructive strategy. Finally, we have become more familiar with the problem domain and feel we have some understanding of how to manipulate problem difficulty and other relevant problem characteristics. Our hypotheses about problem-strategy interactions and the extent to which the Constructive subjects use the 3-dimensional drawing are being pursued in more detail in an experiment currently underway.

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by R.J. Mumaw
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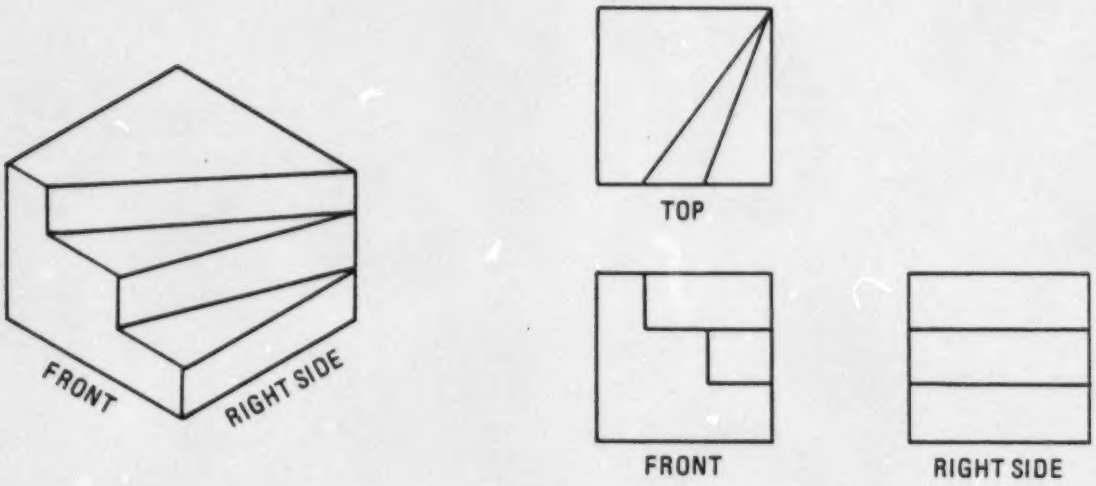


Figure 1

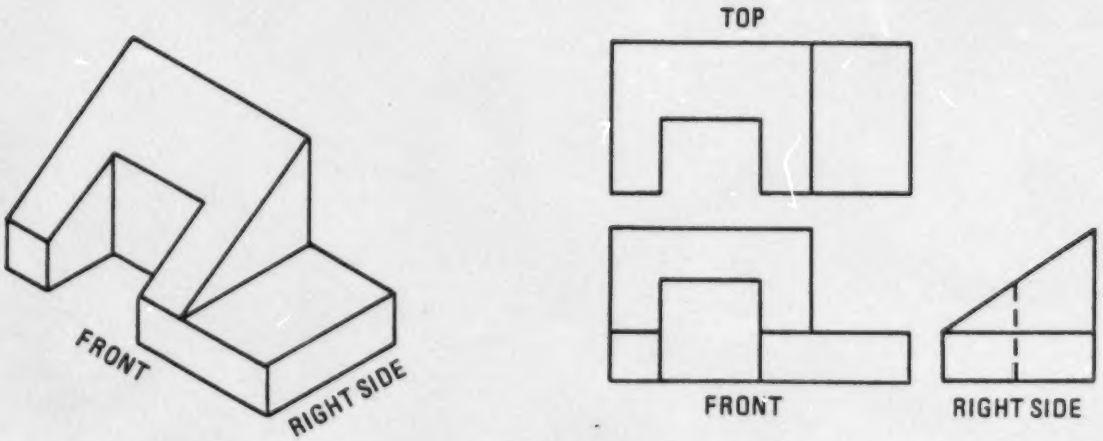
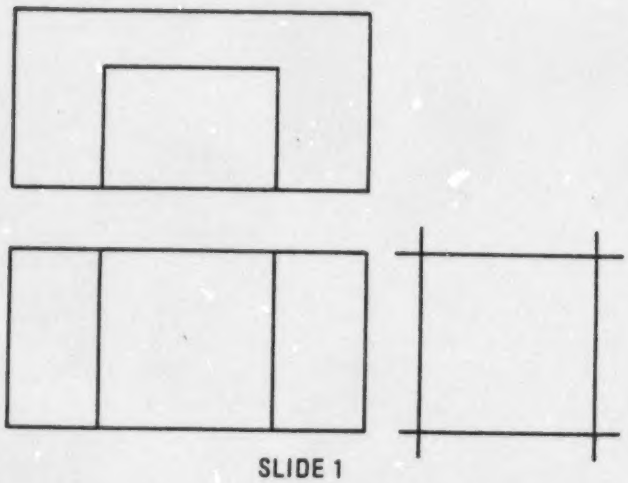


Figure 2



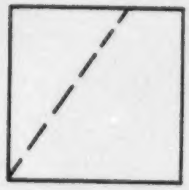


Figure 3

Table 1. The seven dependent measures collected for each trial.

1. number of looks (alternations)
2. total time on trial
3. time of look 1 -- slide 1
4. time of look 1 -- slide 2
5. time of further looks -- slide 1
6. time of further looks -- slide 2
7. accuracy

Table 2. Expected dependent measure patterns for each solution strategy.

	CONSTRUCTIVE	ANALYTIC
1.	number of looks is low.	number of looks is high.
2.	ratio of L1S1/TLTM is high.	ratio of L1S1/TLTM is low.

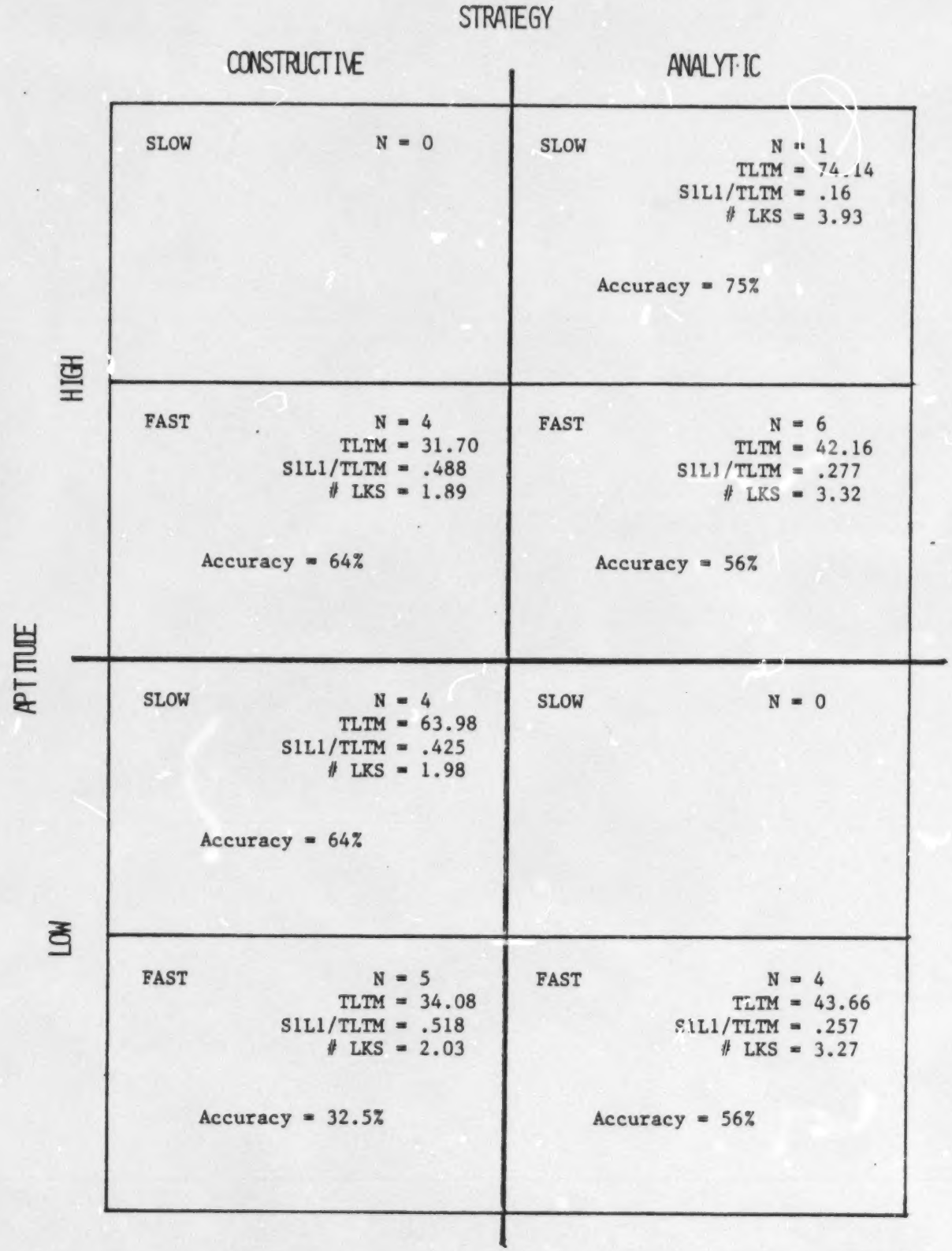
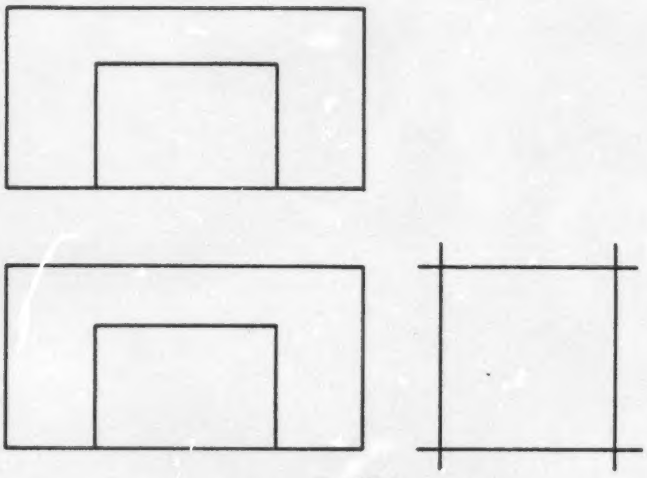
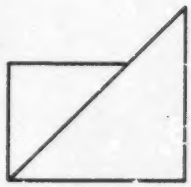


Table 3. Mean accuracy for groups described by strategy, aptitude, and total time to solution. (This analysis was done for only 16 of the 30 items. Items with low discriminate indexes were removed)



SLIDE 1



SLIDE 2

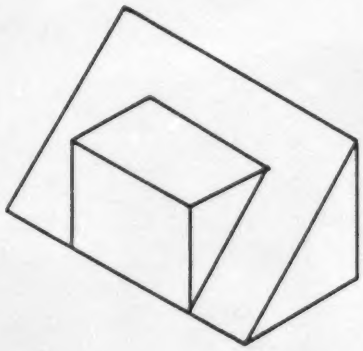
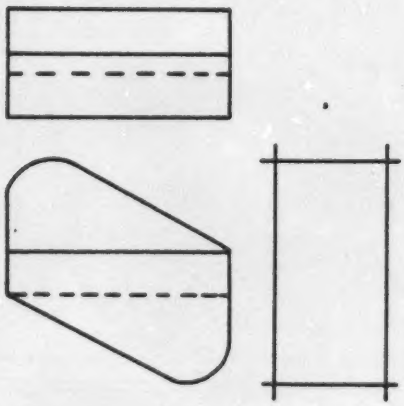
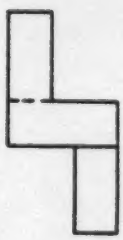


Figure 4



SLIDE 1



SLIDE 2

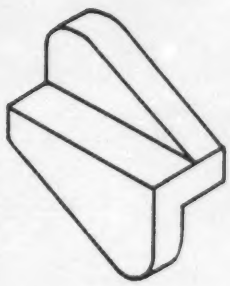


Figure 5